

Design, Development and Evaluation of a Tree Planting-Site-Specific Fumigant Applicator

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Abstract

The goal of this research was to use recent advances in the global positioning system (GPS) and computer technology to apply just the right amount of fumigant where it is most needed (i.e., tree-planting-site-specific application) to decrease the incidence of replant disease, and achieve the environmental and economical benefits of reducing the application of these toxic chemicals. In the first year of this study, we retrofitted a chemical applicator with a high-performance GPS receiver (accuracy in the range of 10 to 20 cm), an embedded controller to read GPS data and control a solenoid valve to implement tree-planting-site-specific fumigant application. Although the system worked well, the results of accuracy tests indicated that the RMS error in position location was 33.5 cm, which was greater than desired. To improve the position location accuracy, a new system was developed during the second year of this study. In this system, the embedded controller which was slow to perform all the necessary computations in real-time was replaced with a higher speed controller. Moreover, a pulse width control module (PWM) and solenoid actuated nozzles were also included to provide precise application rate on demand. Extensive testing indicated that the new system had a RMS error of less than 15 cm. The system was field tested in three almond orchards in California during Fall of 2007. The system performed well in all three locations.

INTRODUCTION

Almond is one of the most important orchard crops amounting to over 2 billion dollars a year (Agricultural Statistics, 2005). The U.S. contributed 86.5% of the world's almond production – about 464,000 metric tons in 2004. Almost all of these almonds are produced on nearly 223,000 ha of almond orchards located in the Central Valley of California. Almond orchards are productive for about 20 to 30 years and need to be replanted at the end of their productive period. If we assume a 25-year orchard life, nearly 8,920 ha of almond orchards need to be replanted every year. When one considers the increasing almond production over the last decade (nearly 32% increase in acreage), the total replant area may be close to 9,000 ha.

Unfortunately, young almond trees replanted at sites of old almond or other stone fruits are often affected by replant disease (RD), a poorly defined soilborne disease complex that stunts, or in severe cases kills, the young trees, resulting in a long-term loss in orchard productivity (Browne et al., 2006). RD is not limited to almonds alone. Peach, plum, nectarine, and other stone fruits also are affected by RD. Even trees such as apples are highly susceptible to RD resulting in substantial economic loss (Traquair, 1984). Pre-plant soil fumigation with methyl bromide (MB), chloropicrin (CP), 1,3-Dichloropropene (1,3-D) or two-way mixtures of CP with MB or 1,3-D are widely practiced as insurance against RD and other replant problems in almonds and stone fruits. Browne et al. (2006) found that CP is particularly effective in controlling RD in almonds. Although the causes of RD are not well-known, parasitic nematodes, oak root fungus, and phytophthora are often associated with RD. The dramatic reduction in RD after soil

fumigation indicates that RD is primarily a biological phenomenon (Mazzola, 1977; Mai and Abawi, 1981; Jaffee et al., 1982; Slykhuys and Li, 1985; Mazzola, 1998). However, fumigation chemicals are expensive and are all toxic general biocides that are heavily regulated at both the national and state levels (U.S. EPA and CalEPA) to minimize environmental exposure and maximize human safety. Besides environmental problems, there is also a serious concern that soil fumigation destroys ecological balance between pathogens and antagonistic organisms (Munnecke, 1984). For these reasons, there is tremendous incentive to reduce fumigant application rates wherever possible.

For orchards, the conventional practice is to fumigate the soil in continuous 2.4-m-wide strips centered on the future tree rows. This results in application rates of approximately 168 kg/ha, depending on the fumigant type and row spacing. Browne et al. (2006) found that application of as little as 0.2 kg of one of these chemicals at planting sites can satisfactorily control replant disease. Since a typical almond orchard has 200 to 350 trees/ha, this site-specific treatment of 0.2 kg/site amounts to an application of 40 to 70 kg/ha of chemicals. This translates to a 58 to 76% reduction in fumigant cost and environmental load, compared to the conventional strip fumigation. This reduction in chemical application is not only beneficial to the environment, but also can save a significant amount of money for the farmers. At a typical fumigant cost of approximately \$5/kg, the savings would range from \$490 to \$640/ha. Assuming an average savings of \$565/ha and that approximately 6000 ha would be appropriately treated with soil fumigation every year, the total annual savings for California almond could reach 3.4 million dollars. When stone fruits such as peaches, nectarines, prunes, and cherries are also included, the estimated savings would be considerably higher. Thus, it is clear that applying a small amount of soil fumigant to control replant disease makes environmental, ecological, and economical sense. However, tree-site treatments are very labor intensive. The labor intensity results largely from a need to auger out and replace soil at the tree site locations before planting so that the hand fumigation probe can be inserted into the soil and fumigant dispersal is facilitated in the loosened soil. Additional labor and worker handling of fumigation machinery is involved in administering the fumigation treatments using hand-held probes. Also, conventional tree-site treatments can involve complications in accurately locating the tree sites before the orchard is marked for planting. It is clear that an innovative engineering solution that can reduce the labor input while delivering the environmental, ecological, and economical benefits of site-specific, precise application of fumigants is necessary to achieve replant disease control in almond orchards. The goal of this research was to use recent advances in the global positioning system and computer technology to apply just the right amount of fumigant (0.2 kg/tree) where it is most needed (i.e., in the neighborhood of each tree planting site) and achieve the environmental and economical benefits of minimizing the application of these toxic chemicals.

Coates et al. (2007) retrofitted a shank type fumigant applicator with a high performance GPS (HPGPS) unit, an embedded processor, and a solenoid valve to accomplish tree-planting-site-fumigant application. Although the system appeared to work quite well, tests indicated that the RMS error in position location was 33.5 cm. Even at this level of accuracy, the fumigant application rate could be reduced by about 50%. However, this design did not fully realize the accuracy level expected from the HPGPS unit (i.e., 10 to 20 cm RMS error). To address this limitation, the following specific objectives were pursued for the 2007 planting season:

1. Further improve the accuracy of the system by improving the hardware and software used in the first prototype developed by Coates et al. (2007),
2. Conduct extensive field tests to ascertain the accuracy and effectiveness of the site-specific fumigant applicator under actual orchard replanting conditions.

MATERIALS AND METHODS

Figure 1 shows the schematic diagram of the new system that was developed during the 2007 season. The system consists of a precision fumigant controller (PFC) that

is connected to a HPGPS unit, an inclination sensor, a pulse width module (PWM), and a Raven flow controller. The PWM unit controlled solenoid actuated nozzles that were located on the applicator shanks to apply desired amounts of fumigant. A tree gridding program that produced the coordinates of the tree planting sites based on the coordinates of the corner trees, row spacing, and tree spacing along the row was developed. Moreover, the gridding program allowed the trees to be planted in a rectangular or diagonal pattern. Figure 2 shows a partial tree-planting-site-map developed for an orchard in Madera, CA. The tree gridding data were uploaded to the PFC and it performed the following tasks:

1. If the inclination sensor indicated that the applicator shanks were in a raised configuration, it performed a global search to determine which row the applicator was approaching. On the other hand, if the inclination sensor indicated that the shanks were in the ground and the HPGPS indicated that the applicator was entering the treatment zone, it connected the Raven controller to the PWM module through a software switch as shown in Figure 1. In fact, it took into account the response time of the system and applicator travel speed and anticipated when it would arrive at the treatment zone in making the decision (i.e., used an appropriate look-ahead value).
2. Similarly it disconnected the PWM from the Raven controller when the fumigant applicator exited the treatment zone using an appropriate look-ahead value.
3. After the planting site of first tree was treated, it searched the neighbors of this tree (maximum of eight trees) to determine which was the next tree-planting site to be treated. The treatment procedure was similar to the one used for the first tree.
4. Once the first and second trees were identified, it determined the direction of travel and recognized the following trees using the planting pattern (i.e., no more search).
5. The tree planting-site-specific application would continue until the inclination sensor indicated that the equipment was raised (e.g., at the end of the row).
6. The PFC enters the global search mode and repeats from step #1 (i.e., repeats the procedure for the next row).

In addition, the applicator could also be operated in a "road test" mode during which PFC ignored the inclination sensor data and allowed to conduct position accuracy tests with shanks lifted up in the air. During operation, the GPS antenna was adjusted such that it was vertically above the fumigant discharge point on the center shank (i.e., no row).

Road Tests for Positional Accuracy

Positional accuracy tests were conducted near the Western Center for Agricultural Equipment (WCAE) on the UC Davis campus using eight marked points spaced 15.2 m apart on a paved surface. The HPGPS unit was used to measure the coordinates of these points and a 1.05 m strip was marked on each side of these eight points in the East-West direction. The PFC was uploaded with the coordinates of these eight points along with the length of the treatment zone (i.e., $2 \times 1.05 = 2.1$ m). The applicator was operated in both the East-West and West-East direction with the shanks raised in the air in the "road test" mode at four different travel speeds (3.2, 4.8, 6.4, and 8 km/h) and the tank filled with water. The water jet was supposed to come on 1.05 m before each of the marked point and was supposed to turn off 1.05 m after the same point. However, due to the system response time, water jet would come on and go off at different locations than expected resulting in error. These positional errors were measured to determine the appropriate look-ahead-values (LAV) to minimize positional error irrespective of travel speed. Appropriate LAVs (one corresponding to turning the system "on" and the other corresponding to turning the system "off") were uploaded to the PFC and another set of road tests was conducted to determine the final positional accuracy of the system.

Field Tests for Positional Accuracy

Field tests were also conducted near WCAE. Thirty grid points were marked off in a rectangular area consisting of six rows spaced 15.2 m apart with five tree sites located 12.2 m apart along each row. These grid points along with the application zone

length of 2.1 m were uploaded to the PFC. The applicator was operated with the shanks in the soil and colored liquid in the tank. Center nozzle was used as a marker. All field tests were conducted at 4.8 km/h. Tests were conducted along the east-west as well as north-south direction. The colored spray was used to measure the positional accuracies under field conditions.

Orchard Tests

Following the road test, the system was used in three orchards in California (Arbuckle, Madera, and Parlier) to perform tree-planting-site-specific fumigation. In order to accomplish these tasks, orchard coordinates were measured using the HPGPS unit. These corner coordinates were input into the gridding program along with the row spacing, tree spacing along the row and planting pattern. The tree-planting-site map was uploaded to PFC and the applicator was operated in each of the three orchards.

RESULT AND DISCUSSION

Preliminary tests of the tree-planting-site-specific fumigant application near WCAE on the UC Davis campus indicated that the system appeared to work quite well. However, it was necessary to make sure that the system was capable of applying the fumigants, where needed, accurately. Results of the road and field tests that were conducted to verify the accuracy of the system are presented below.

Road Test Results

Figure 3a shows the road test results when no look-ahead-values were used. The results show that the position location error increased as the speed of the applicator increased both for turning the system "on" (coefficient of determination or r^2 value of 0.90) and for turning the system "off" (r^2 value of 0.89). The slopes of these two lines (91 mm-h/km or 328 ms and 88 mm-h/km or 317 ms respectively) indicate the appropriate look-ahead values. Figure 3b shows the effect of implementing a LAV of 328 ms for turning the system "on" and a LAV of 317 ms for turning the system "off." The very low r^2 values for both turning the system "on" and for turning the system "off" indicate that the accuracy is independent of the applicator ground speed. However, the intercept values indicate that there is a slight offset between the GPS antenna and the fumigant discharge point on the center shank (i.e., 36 mm for turning the system "on" and 51 mm for turning the system "off"). However, these values are well below the accuracy of the HPGPS system used.

Field Test Results

Table 1 presents the field test results. These results indicate that the system tended to turn "on" and "off" early (about 19 to 26 cm) in both the east-west and north-south directions. Even a slight error in positioning the colored water discharge jet could result in errors of this magnitude. Moreover, the movement of soil at the surface caused by the passage of the shank also contributed to this error. The RMS error (i.e., standard deviation) was in the range of 12 to 15 cm for all the tests. These error values are within the range (10 to 20 cm) expected for the HPGPS system used. The application zone length was about 221 cm in both east-west and north-south directions (i.e., a 3.8% error compared to the expected value of 213 cm). These results were thought to be acceptable for this system and the system was taken to three orchards in California to perform tree-planting-site specific fumigant application.

Orchard Tests

The system worked quite well during the orchard tests in Arbuckle and Madera. There were some GPS signal quality issues in Parlier during the first day of test. However, the system performed fine on the following day. The final results of these tests will be known when the almond tree growth parameters would be measured in the coming years.

CONCLUSIONS

Based on this study in which a shank-type fumigant applicator was used to develop a tree-planting-site-specific fumigant system, we reached the following conclusions:

1. The HPGPS based precision fumigant application system worked satisfactorily during the road and field tests conducted near WCAE on the UC Davis campus.
2. The look-ahead-values were found to be 328 ms for turning the system "on" and 317 ms for turning the system "off." When these look-ahead-values were properly accounted for, the position location accuracy of the system was independent of the speed of the applicator.
3. Field test results indicated that the RMS error in locating the position was less than 15 cm and the application zone length was very close to the desired value (about 3.8% error).

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Tables

Table 1. Positional accuracy results obtained from field tests conducted near WCAE on the UC Davis campus when the applicator was operated in the east-west as well as north-south direction.

	East-West direction		North-South direction	
	Mean (cm)	Standard deviation (cm)	Mean (cm)	Standard deviation (cm)
Turn-on	-26.5	12.1	-22.9	14.9
Turn-off	-19.0	12.9	-15.0	14.9
Actual application zone length (Desired value = 213 mm)	220.6	9.1	221.	14.1

Figures

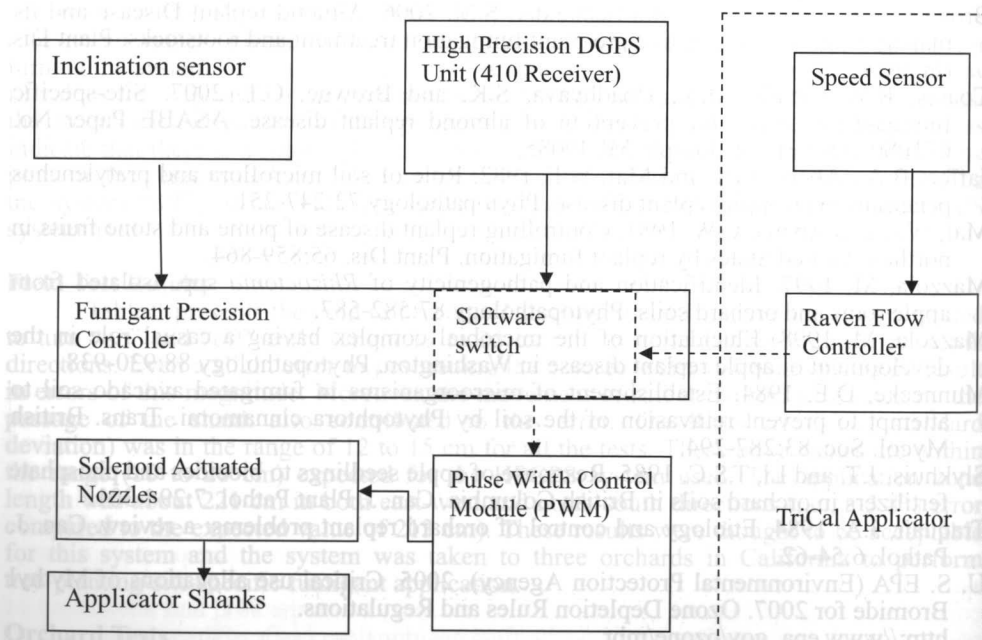


Fig. 1. Schematic diagram of the tree-planting-site-specific fumigant application system.

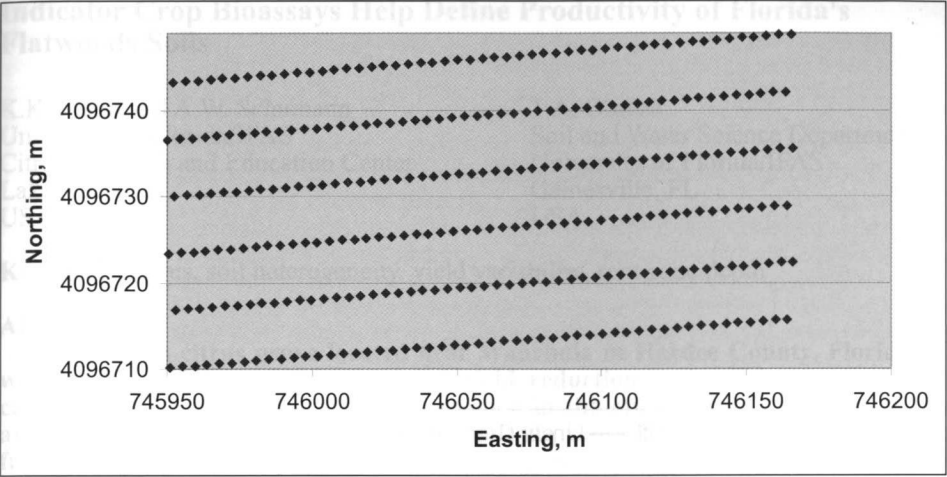


Fig. 2. A partial tree planting map for an orchard in Madera, CA.

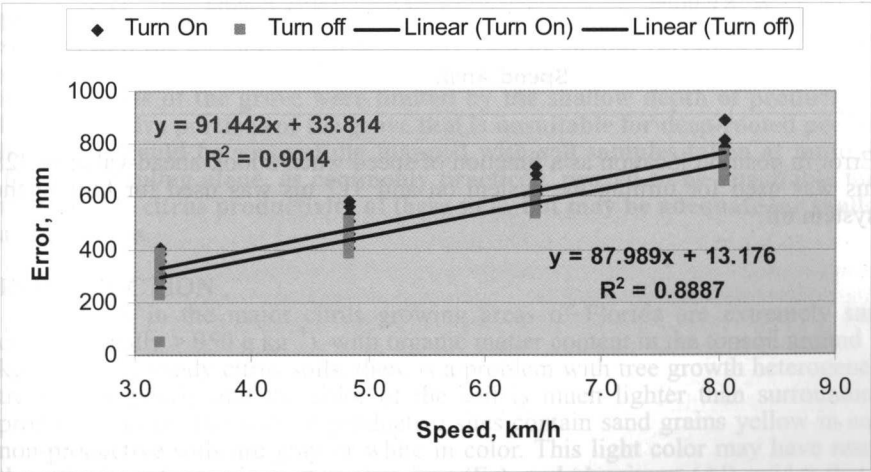


Fig. 3A. Error in position location as a function of applicator ground speed when no look-ahead-values were used.

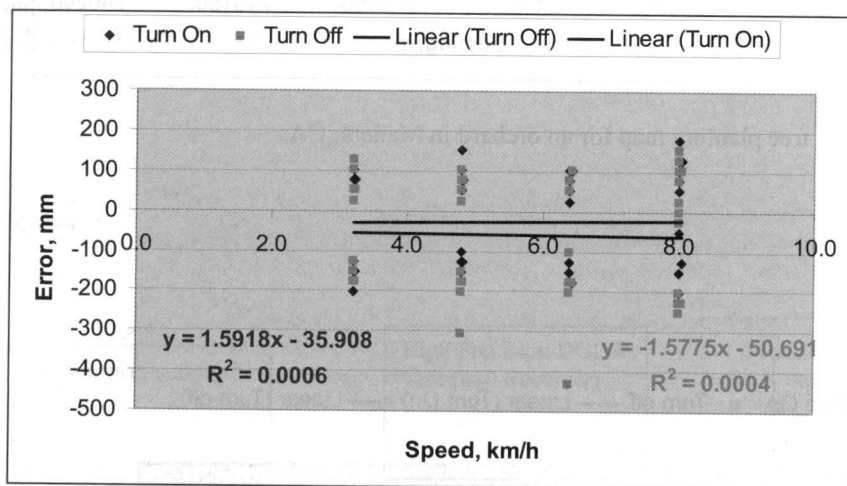


Fig. 3B. Error in position location as a function of speed when a look-ahead-value of 328 ms was used for turning the system on and 317 ms was used for turning the system off.



Fig. 3A. Error in position location as a function of applicator ground speed when no look-ahead-values were used.